Materials Science and Engineering A 435–436 (2006) 54–61

MATERIALS SCIENCE & ENGINEERING A

www.elsevier.com/locate/msea

Processing and microstructure of submicron WC–Co particulate reinforced Cu matrix composites prepared by direct laser sintering

Dongdong Gu*, Yifu Shen

College of Materials Science and Technology, Nanjing University of Aeronautics and Astronautics, 29 Yudao Street, 210016 Nanjing, PR China

Received 31 March 2006; received in revised form 22 May 2006; accepted 25 July 2006

Abstract

In the present work, the submicron WC–10% Co particulate reinforced Cu matrix composites were prepared using direct metal laser sintering (DMLS). The phase, composition, and microstructure of the laser sintered samples were characterized. It shows that the WC reinforcing particulates are smoothened and refined, exhibiting compatible metallurgical interfaces with the matrix. The effects of processing parameters such as laser power, scan speed, and layer thickness on microstructures and properties of the laser sintered samples were investigated. It is found that below 700 W, increasing the laser power leads to a higher densification with an improved bonding ability between the reinforcement and the matrix. There exists a critical scan speed of 0.04 m/s which corresponds to the transition of pushing to trapping of particulates by the advancing solid/liquid interface, above which the distribution of particulates becomes more homogeneous with increasing the scan speed. A proper decrease in the powder layer thickness below 0.30 mm permits higher sintered densification and attendant mechanical properties.

Keywords: Metal matrix composites (MMCs); Rapid prototyping (RP); Direct metal laser sintering (DMLS); Microstructure; WC–Co; Cu

1. Introduction

Direct metal laser sintering (DMLS) is a typical rapid prototyping (RP) technique, which enables the quick production of complex shaped three-dimensional (3D) parts directly from metal powder [1–3]. The DMLS technique creates parts in a layer-by-layer fashion by selectively fusing thin layers of a loose powder with a scanning laser beam. Each scanned layer represents a cross-section of the object's mathematically sliced CAD model. After consolidation of one cross-section, a fresh layer of powder is deposited and the process is repeated until a 3D part is completed. This technique competes effectively with other conventional manufacturing processes when the part geometry is complex and the production run is not large [4]. In fact, the DMLS process gives a great promise for the net-shape fabrication of functional prototypes and the small volume production of tooling for injection molding and die casting [5,6].

WC–Co, a well-known hard metal, combines favorable properties such as high strength, high hardness, wear resistance, and reasonable fracture toughness [7]. Copper is characterized by excellent electrical and thermal conductivities as well as outstanding resistances to fatigue and corrosion [8]. In order to combine their superior physical properties, the development of WC–Co/Cu metal matrix composites (MMCs) is of significance. Generally, such MMCs are produced by conventional casting or powder metallurgy methods, which are productive and can obtain fully dense parts [9,10]. However, conventional techniques, which need expensive and dedicated tools such as moulds or dies, are not suitable for small volume production and complex shapes [11]. Fortunately, the DMLS process, due to its flexibility in materials and shapes, exhibits a great potential for creating complex 3D MMCs that cannot be developed by other conventional means. The DMLS, generally, uses a mixture consisting of high melting point metal powder, acting as structural particles, and low melting point metal powder, as a binder. Laser radiation selectively melts the binder and, subsequently, the liquid metal is driven by capillary forces into the voids between the structural particles. Consolidation of the solid–liquid mixture is attained by solidification of the liquid metal on cooling. So far, considerable metal powder materials have been investigated for the use of DMLS, including pre-alloyed metal powders (e.g. alloy 625 [12], Ti6Al4V [13], stainless steel [14], high speed steel [15], low carbon steel [16], and tool steel [17])

* Corresponding author. Fax: +86 25 52112626.
E-mail addresses: dongdonggu@hotmail.com, dongdonggu@nuaa.edu.cn (D. Gu), yifushen@nuaa.edu.cn (Y. Shen).

0921-5093/$ – see front matter
doi:10.1016/j.msea.2006.07.105

and multi-component metal powders (e.g. Ni–CuSn–CuP [18], Ni–alloy–Cu [19], Cu–SCuP [8,20], Cu–CuSn–CuP [21,22], iron-graphite [2], Fe–Ni–Cu–Fe_3P [23], and Fe–C–Cu–Mo–Ni [6]). However, not much previous work has been reported on the basic principles of the fabrication of bulk MMCs using direct laser sintering. In fact, due to the complex nature of DMLS, which involves multiple modes of heat, mass, and momentum transfer [2,3], common problems associated with DMLS such as balling effect and curling deformation are still difficult to completely overcome, which makes it difficult to process complex near net-shaped MMCs meeting the performance and cost requirements for industrial standards.

Recently, we have attempted to prepare submicron WC–Co particulate reinforced Cu matrix composites by the DMLS process [24,25]. It has been found that the densification level and mechanical properties of the laser processed MMCs were susceptible to the crack formation between the reinforcing particles and the matrix, which in turn depended on both powder characteristics and processing conditions. As a further step in obtaining high performance MMCs with controllable microstructures, the present study employs the DMLS process to prepare a series of WC–Co/Cu MMCs. The effects of processing parameters on the densification, microstructure, and resultant mechanical properties of the laser processed bulk MMCs were highlighted.

2. Experimental procedure

2.1. Materials

Electrolytic 99% purity Cu powder with round dendrite shape and mean particle size of 15 μm, and WC–10% Co composite powder with irregular shape and mean equivalent spherical diameter of 0.6 μm were used in this study. The WC–Co composite powder, as shown in Fig. 1(a), was synthesized using a novel “spray drying and fixed bed” technique. Powder preparation involved the following steps: (1) spray drying a precursor solution containing AMT-$Co(NO_3)_2$; (2) burning out the precursor powder to obtain complex oxide powder; (3) carbothermic reduction of the ball-milled powder to produce WC–Co composite powder [26,27]. The two components were mixed according to Cu:WC–Co weight ratio of 70:30. Powder dispersion was performed in a horizontal ball mill with a vacuum-pumping system at a rotation speed of 150 rpm for 60 min, with balls to powders weight ratio of 5:1. The characteristic morphology of a homogenously mixed powder system is shown in Fig. 1(b).

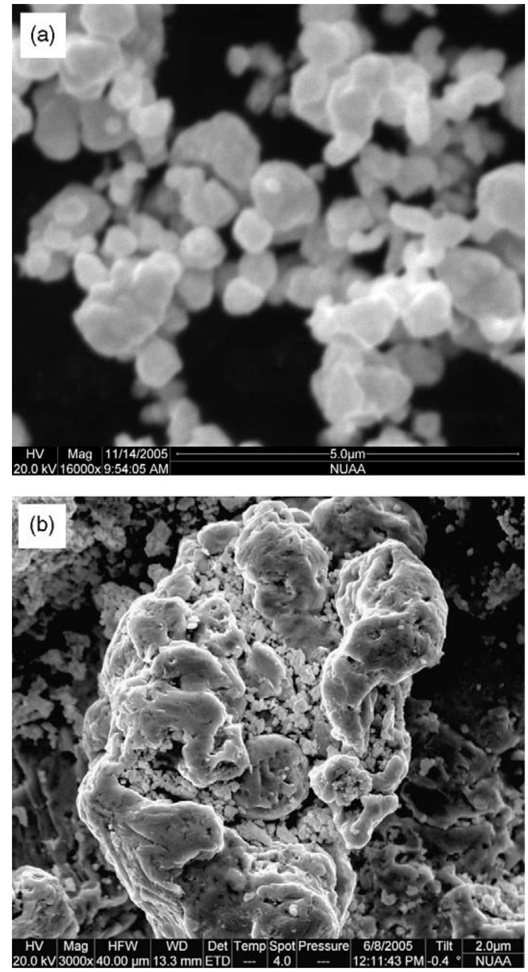

Fig. 1. SEM images showing characteristic morphologies of the WC–Co composite powder (a) and the mixed powder system (b).

2.2. Processing

The DMLS apparatus used in this experiment, as shown in Fig. 2, mainly consisted of a continuous wave Gaussian CO_2 laser with a maximum output power of 2000 W, an automatic powder delivery system, and a computer system for process control. Details of the DMLS process are summarized as follows. First, a steel substrate was placed on the building platform and leveled. Then, a thin layer of the loose powder was spread on the substrate by the roller. Subsequently, a laser beam scanned the powder bed surface to form a layer-wise profile according to the CAD data of the part. The similar process was repeated and the part was produced in a layer-by-layer fashion until completion. The entire sintering process was performed in air at room temperature. The processing conditions investigated were as follows: spot size of 0.30 mm, laser power of 500–800 W,

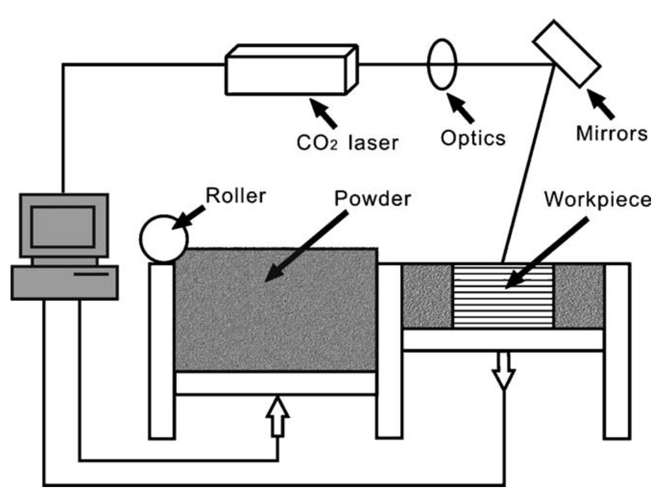

Fig. 2. Schematic diagram of the direct laser sintering apparatus.